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A time-geographical approach to biogas potential analysis of China

I-Shin Chang [a,1], Jing Wu [b,*], Changbo Zhou [c,2], Mingmin Shi [b], Yanxia Yang [a]

[a] College of Environment and Resources, Inner Mongolia University, # 235, University W. Road, Saihan District, Huhhot 010021, Inner Mongolia, PR China
[b] College of Environmental Science and Engineering, Nankai University, # 94, Weijin Road, Nankai District, Tianjin 300071, PR China
[c] Cleaner Production Centre, Chinese Research Academy of Environmental Sciences, # 8, Dayangfang, Anwai, Chaoyang District, Beijing 100012, PR China

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ABSTRACT

Biogas is a renewable energy source by converting biomass energy into convenient, accessible and clean energy for diverse applications. In China, with vast grassland and arable land, the biogas potential is quite high, owing to tremendous amount of organic waste from agriculture and husbandry. Yet, without proper and timely treatment, the organic waste has been resulting in severe environmental hazards and health risks to take away the major part of economic achievements from agriculture and husbandry. It has been the important task to speed up the development of biogas industry and to fully extend the utilization of biogas for both central and local governments, with great efforts and enormous investment. In order to facilitate the development of biogas industry, to increase the exploitation and utilization of biogas, and to improve the return on investment on biogas production, the purpose of this research is to evaluate the biogas potential of crop straw and livestock manure through time-series analysis and geographical approach. Biogas potential of different crops and animals in various regions are estimated to learn the geographical characteristics and regional differences. In addition, actual biogas production and biogas production from large- and medium-scale biogas engineering projects are compared with biogas potential to learn the exploitation and utilization rate of biogas. Biogas potential density and biogas production density are also analyzed to learn the biogas potential efficiency and biogas production efficiency in various regions. Finally, some recommendations are provided for instituting corresponding policies and strategies to promote the development of biogas industry in China.

Contents

* Corresponding author. Tel./fax: +86 22 2350 8348; Mobile: +86 13 82138 0831.
E-mail addresses: heartchang@126.com (I.-S. Chang), wujing@nankai.edu.cn (J. Wu), zhoucb@craes.org.cn (C. Zhou), shimingm@mail.nankai.edu.cn (M. Shi), sunshine__2009@yeah.net (Y. Yang).
[1] Mobile: +86 15 0483 63776.
[2] Mobile: +86 13 9105 52291.

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1. Introduction

As energy demands sharply rising along with rapid economic development, energy security has been one of the major tasks for every country in the world, whilst fossil fuel energy sources are depleting fast due to excessive exploitation and utilization. Hence, exploring new, reliable, renewable and sustainable energy sources has become one of the key quests to tackle the crises of energy shortage, worldwide. In the meantime, energy conservation and emission reductions are set as two primary strategies and countermeasures in responding to climate change, which have imposed stringent restrictions and requirements on energy consumption and energy efficiency. Under such context, with great potential for energy conservation, biomass energy (bioenergy), the conventional, reliable, renewable, and clean energy source derived from plant or animal waste, has been recognized as the viable solution in resolving both energy and environmental issues, at the same time.

Biogas, an efficient and convenient method to recover energy from waste biomass for cooking, heating, fueling, power generation and various purposes, is the gas produced by microbial degradation of organic matter through anaerobic process. Biogas plays the significant role in improving energy structure, environmental quality and health conditions, reducing greenhouse gases emissions, and promoting economic and social sustainable development in rural areas. In Europe, the United States and other developed countries, biogas technology has been identified as an effective way of dealing with agricultural waste and livestock manure for waste resources recycling. Right now, the development of biogas technology in Europe is the most advanced and mature in the world, with extensive applications.

In China, the promotion of biogas applications was initiated in 1950s. The development of biogas industry was quite slow and backward before 1990s. Nevertheless, as the biggest agricultural country with about 800 million farmers, the construction and development of rural areas has always been one of the predominant tasks for the Chinese government. In 1982, the first official document of the year (the Central-1 document), issued by the State Council and the Central Committee of the Communist Party of China (the CCCPC), was regarding the promotion of village reform, which is the first Central-1 document concerning agriculture, village and farmers (the 3-Agros). It is important to realize that the Central-1 document is the most important outlines and guiding principles for the work plan of the year, nationwide, which indicates the emphasis of yearly work preferences for the governments. Furthermore, the 3-Agros has been the focus of the Central-1 document for the next four consecutive years, until 1986. Entering into the 21st century, once again, close attention has been paid to agricultural development and rural construction, where biogas development has acquired numerous considerations and great supports from both central and local governments. Since 2003, the 3-Agros has been re-elevated as the focal point of the Central-1 document for more than one decade, as shown in Table 1, in which the construction of village biogas engineering projects has been listed as one of the major tasks. Moreover, many laws, regulations, ordinances, plans and reports have put biogas development as one of the primary targets for the development of renewable energy, as shown in Table 2. And, the investment on biogas production from the Chinese government has been increasing considerably since the 21st century, as shown in Table 3·[1].

Indeed, with more than 1.2×10^6 km^2 of arable land and 3.9×10^6 km^2 of grassland, the biogas potential in China is huge. Through time-series analysis and geographical approach, the purpose of this study is to evaluate the biogas potential of both agricultural waste (straw) and livestock manure (excrement and urine) in various districts and provinces/municipalities, from 2007 to 2011. Biogas potential of different crops and livestock are also compared to learn the geographical characteristics and regional differences. The gaps between the theoretical biogas potential and actual biogas production are then analyzed to find out the exploitation rate of biogas potential. In addition, the biogas production from large- and medium-scale biogas engineering projects is compared with actual biogas production to assess the utilization rate. Furthermore, biogas production is compared with capital investment to discover the return on investment. At last, some recommendations are provided as references for instituting strategies and procedures to promote the development of biogas industry in China.

Table 1
List of the Central-1 issued by the State Council and the CCCPC.

Category	Year	Title
The first offic1al document issued by the State Council and the Central Committee of the Communist Party of China	2013	Some Opinions Concerning Hastening the Development of Modern Agriculture and Enhancing the Rural Development Vigor
	2012	Some Opinions Concerning Hastening the Promotion of Agricultural Technology Innovation and Continuously Enhancing the Guarantee Capacity of Agricultural Products Supply
	2011	The Decisions on Hastening Water Conservancy Reform and Development
	2010	Some Opinions Concerning Amplifying Comprehensive Urban and Rural Development and further Enhancing the Foundation of Agricultural and Rural Development
	2009	Some Opinions Concerning Promoting Stable Agricultural Development and Continuously Increasing Farmer's Income
	2008	Some Opinions Concerning Realistically Enhancing Agricultural Infrastructure to Further Promote Agricultural Development and Increase Farmer's Income
	2007	Some Opinions Concerning Positively Developing Modern Agriculture and Solidly Promoting the Construction of Socialist New Rural Areas
	2006	Some Opinions Concerning Promoting the Construction of Socialist New Rural Areas
	2005	The Opinions Concerning Some Policies in Enhancing Rural Construction to Improve Overall Agricultural Productivity
	2004	The Opinions Concerning Some Policies in Promoting Farmer's Income Growth
	2003	The Opinions Concerning Fully Promoting the Experimental Reform of Rural Taxes and Administrative Charges
	1986	The Deployment of Village Work in 1986
	1985	Ten Policies to Promote and Energize Village Economy
	1984	Notice on the Village Work in 1984
	1983	Some Issues Concerning the Policies for Contemporary Village Economy
	1982	Summary of National Village Work Meeting

Table 2
List of laws, regulations, ordinances, plans and reports to promote the development of biogas.

Category	Year	Issuer	Title
Law	2012	The Standing Committee of the 11th National People' s Congress	The Amendment of the Agriculture Law of the People's Republic of China
	2009	The Standing Committee of the 11th National People' s Congress	The Amendment of the Renewable Energy Law of the People's Republic of China
	2007	The Standing Committee of the 10th National People' s Congress	The Amendment of the Energy Conservation Law of the People's Republic of China
	2005	The Standing Committee of the 10th National People' s Congress	The Renewable Energy Law of the People's Republic of China
Plan & report	2013	The State Council	The Energy Development Plan for the 12th Five-Year Period
	2012	National Development and Reform Commission	The Renewable Energy Development Plan for the 12th Five-Year Period
	2012	The Ministry of Agriculture	National Agricultural and Rural Economic Development Plan for the 12th Five-Year Period
	2011	National Development and Reform Commission, The Ministry of Agriculture, The Ministry of Finance	The Implementation Schemes of Comprehensive Utilizations of Crop Straw for the 12th Five-Year Period
	2010	The Ministry of Agriculture	National Crop Straw Resources Survey and Evaluation Report
	2008	National Development and Reform Commission	The Renewable Energy Development Plan for the 11th Five-Year Period
	2007	The Ministry of Agriculture	National Agricultural Biomass Energy Industry Development Plan for 2007 to 2015
	2007	The Ministry of Agriculture	National Rural Biogas Construction Plan for 2006 to 2010
	2007	The State Council	The Mid- and Long-term Development Plan for Renewable Energy
	2006	The Ministry of Agriculture	National Agricultural and Rural Economic Development Plan for the 11th Five-Year Period
Ordinance	2002	The State Council	The Ordinance on Returning Farmland to Forest

2. Methodology

In order to extract significant information and other characteristics of the time-series data, a time-series analysis is applying various methods to discern where there is some pattern in the time-series data collected, with the intention of short-term prediction and forecasting. A time-series analysis often involves trend assessment, seasonality assessment, periodic and irregular fluctuation assessment, and/or correlation assessment. A time-series analysis can be applied to real-valued, continuous data, discrete numeric data, or discrete symbolic data.

A geographical approach is about understanding patterns and processes in space and the distinctiveness of places, where spatial concepts are the cores of the analysis. In order to understand and itemize the elements, characteristics and uniqueness arising in various places, a geographical approach adopts analytical procedures to study, understand and resolve diverse issues. By using geographic information system (GIS) as the platform, a geographical approach can generate more detailed information regarding the geographical distributions and differences, which will be quite important in solving problems. Through the integration of time-series analysis and geographical approach, the purpose of this study is to investigate the temporal and spatial distributions and differences of biogas production in China.

In this study, all provinces and municipalities are grouped into six districts, conventionally, including North district, North East

Table 3
Investment on biogas production from the Chinese Government.

Year	1996–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
¥ (10^6)	55.4	131.0	310.0	1030.5	1032.5	1030.0	2500.0	3000.0	4500.0	5000.0	5200.0	4300.0	4000.0

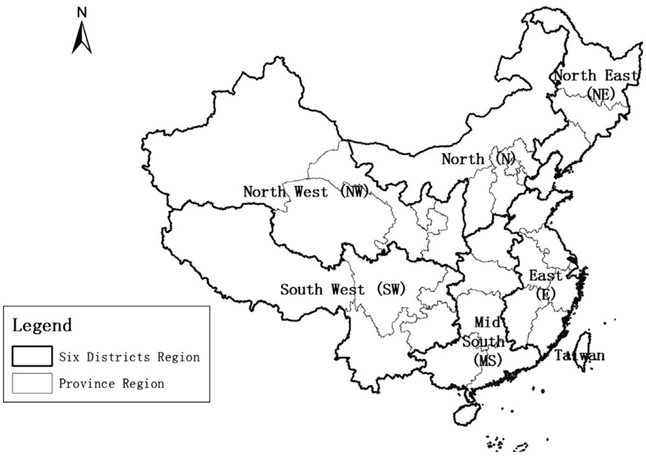

Fig. 1. Geographical allocation of districts and provinces/municipalities.

district, East district, Mid-South district, South West district and North West district, according to similar geographical and meteorological characteristics, as shown in Fig. 1. For agricultural waste, five major crops, such as food crops (paddy, wheat, corn, bean and tuber), cotton, oil crops (peanut, rape and sesame), bast fiber plants and sugar crops (sugarcane and beet) are evaluated for their straw production and biogas potential. After carefully review on previous researches and studies, straw/crop ratio, straw availability, total solids (TS) content, and biogas yield coefficient of different crops are then determined, as shown in Table 4 [2–20]. For livestock manure, seven animals, including cattle, horse, donkey, mule, camel, pig, and sheep, are evaluated for their manure production and biogas potential. Again, livestock manure coefficient, total solids content, and biogas yield coefficient are determined based on literature review [3,8,11,15,20–32], as shown in Table 4.

Biogas potentials of straw and livestock manure were calculated according to the following equations

$$BP_S = P_C \times R_{SC} \times A \times TS_S \times BPF_S \quad (1)$$

where BP_S is the biogas potential of straw; P_C is the crop production; R_{SC} is the straw/crop ratio; A is the straw availability; TS_S is the total solids content of straw; and BPF_S is the biogas yield coefficient of straw.

$$BP_L = P_L \times MF_L \times TS_L \times BPF_L \quad (2)$$

where BP_L is the biogas potential of livestock manure; P_L is the livestock production; MF_L is the livestock manure production factor; TS_L is the total solids content of livestock manure; and BPF_L is the biogas yield coefficient of livestock manure.

$$BP_T = BP_S + BP_L \quad (3)$$

where BP_T is the combined biogas potential of straw and livestock manure.

All raw data are acquired and collected from the China Statistical Yearbook (from 2008 to 2012) [33], the Agricultural Statistics Yearbook (from 2008 to 2012) [34], the China Statistical Yearbook on Environment (from 2008 to 2012) [35], and the Report on the Environmental Status in China (from 2008 to 2012) [36], and then processed according to the parameters provided in Table 4, and finally calculated based on the equations listed in the above. Due to the gaps between numbers are too big to use the Equal Spacing Method, the Natural Breakpoint Method is applied to some figures for better presentation.

3. Biogas resources assessment

3.1. Land resources

3.1.1. Arable land

The total area of arable land in China is around 1.221×10^6 km^2 (about 12.71% of entire area of China), which is roughly evenly distributed within six districts, for example, North district (15.23%), North East district (17.57%), East district (19.92%), Mid-South district (19.78%), North West district (15.64%), and South West district (11.86%). For province, Heilongjiang (118.30×10^3 km^2), Henan (79.26×10^3 km^2), Shandong (75.15×10^3 km^2), Neimenggu (71.47×10^3 km^2), and Hebei (63.17×10^3 km^2) are the top five provinces with bigger arable land. Nevertheless, Shandong (48.86%), Henan (47.46%), Jiangsu (46.43%), Anhui (41.02%), and Tianjin (39.04%) are the top five provinces with higher percentage of arable land, as shown in Fig. 2(a) and (d).

3.1.2. Grassland

The total area of grassland in China is about 3.928×10^6 km^2 (nearly 40.88% of entire area of China), which is mainly distributed within three districts, including South West district (31.61%), North West district (30.48%), and North district (22.56%). For province, Tibet (820.52×10^3 km^2), Neimenggu (788.02×10^3 km^2), Xinjiang (572.59×10^3 km^2), Qinghai (363.70×10^3 km^2), and Sichuan (209.65×10^3 km^2) are the top five provinces with bigger grassland land. Moreover, Tibet (66.82%), Neimenggu (66.61%), Qinghai (50.35%), Ningxia (45.39%), and Sichuan (43.05%) are the top five provinces with higher percentage of grassland, as shown in Fig. 2(b) and (e).

3.1.3. Sum of arable land and grassland

The total area of arable land and grassland in China is about 5.149×10^6 km^2 to denote that there is great potential of organic waste production from agriculture and husbandry. The total area of arable land and grassland, covering nearly 53.58% of entire area of China, is mainly distributed within three districts, including South West district (27.83%), North West district (26.07%), and North district (20.82%). For province, Neimenggu (859.52×10^3 km^2), Tibet (824.14×10^3 km^2), Xinjiang (613.83×10^3 km^2), Qinghai (369.12×10^3 km^2), and Sichuan (269.12×10^3 km^2) are the top five provinces with bigger area of arable land and grassland. And, Henan (74.01%), Neimenggu (72.66%), Tibet (67.11%), Ningxia (62.07%), and Jilin (60.71%) are the top five provinces with higher percentage of arable land and grassland, as shown in Fig. 2 (c) and (f).

3.2. Straw resources

In China, the crop productions are mainly concentrating on food crops, especially for grains (including paddy, wheat, and corn), and sugarcane [33,34]. In general, the annual crop production has been continuously growing from 2007 to 2011, especially for corn, as shown in Table 5. The straw production potential is

Table 4
Some parameters for crop straw and livestock manure.

Crop straw

Group	Type	Item	Straw/crop ratio (kg/kg)	Straw availability (%)	Total solids content (TS) (%)	Biogas yield coefficient (m^3/t TS)
Food crops	Grains	Paddy	1.0	60	80	250
		Wheat	1.1			
		Corn	2.0			
	Beans		1.7			
	Tubers		1.0			
Cotton			3.0			
Oil crops		Peanut	1.5			
		Rape	3.0			
		Sesame	2.0			
Bast fiber plants			1.7			
Sugar crops		Sugarcane	0.1			
		Beets	0.1			

Livestock manure

Livestock	Manure (t/yr)	Total solids content (TS) (%)	Urine (t/yr)	Total solids content (TS) (%)	Total TS per capita (t/yr)	Biogas yield coefficient (m^3/t TS)
Cattle	10.950	20.0	10.950	0.6	2.256	200
Horse	5.475	20.0	8.213	0.6	1.144	200
Donkey	3.103	20.0	3.103	0.6	0.639	200
Mule	3.103	20.0	3.103	0.6	0.639	200
Camel	9.125	20.0	9.125	0.6	1.880	200
Pig[a]	1.800	20.0	3.000	0.4	0.372	300
Sheep	0.730	20.0	0.365	0.4	0.147	200

[a] The on-hand period for pig is 300 days.

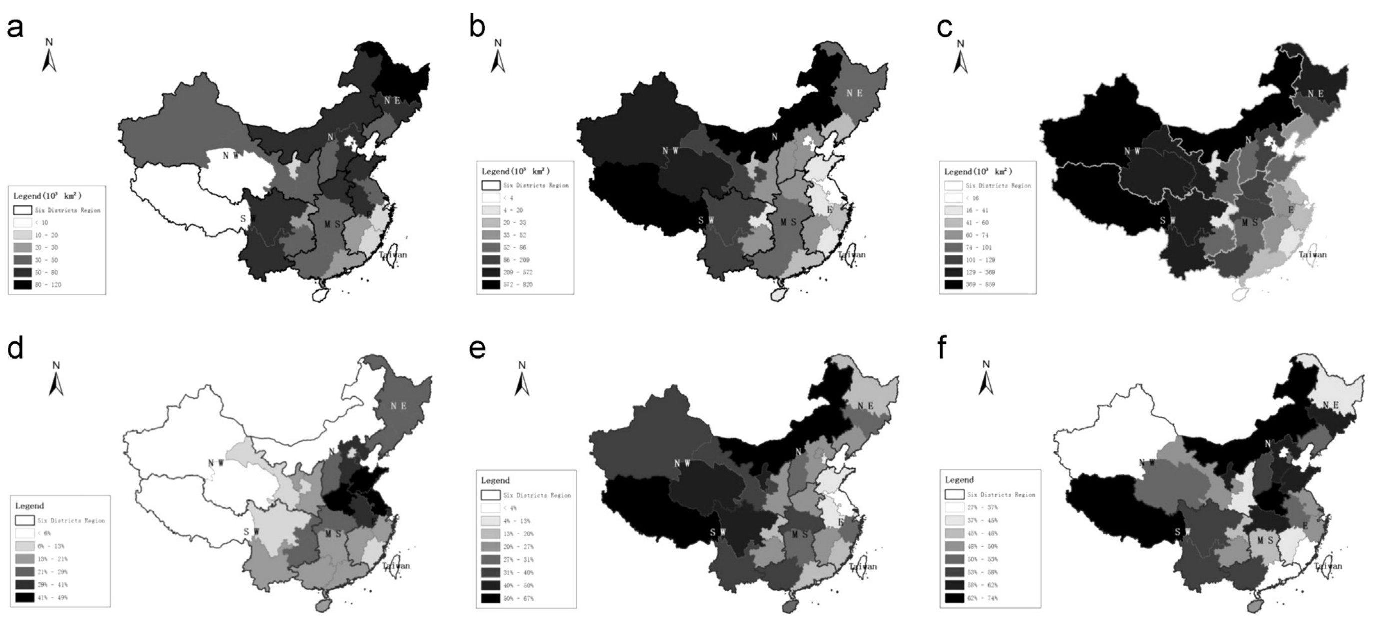

Fig. 2. Allocation of arable land, grassland, and arable land+grassland in various regions. (a) Allocation of arable land. (b) Allocation of grassland. (c) Allocation of arable land+grassland. (d) Percentage of arable land. (e) Percentage of grassland and (f) Percentage of arable land+grassland.

then calculated based on the parameters listed in Table 4. From 2007 to 2011, the biggest contribution to straw production potential is primarily from corn (41.70%), followed by paddy (23.73%) and wheat (15.33%). Since the straw/crop ratio of sugarcane is only 0.1 kg/kg, which is less than 10% of that of grains, the contribution to straw production potential from sugarcane is quite small in comparing with that from grains, as shown in Fig. 3.

For districts, the major contributor to straw production is coming from Mid-South district with a contribution of 24.37%, followed by East district (23.80%) and North East district (18.20%). For province, the largest contribution to straw production is coming from Henan (10.37%), followed by Shandong (8.82%), Heilongjiang (8.55%), Hebei (6.08%), and Jilin (5.92%), as shown in Table 6.

3.2.1. Corn

For district, the biggest straw production potential is from North East district with a contribution of 30.57%, followed by North district (22.24%) and East district (14.43%). For province,

Heilongjiang has the highest straw production potential with an input of 11.95%, followed by Jilin (11.78%), Shandong (11.19%), Henan (9.58%), and Hebei (8.77%), as shown in Table 7.

3.2.2. Paddy

For district, the biggest straw production potential is from Mid-South district with a contribution of 35.29%, followed by East district (33.10%) and South West district (15.75%). For province, Hunan has the highest straw production potential with an input of 13.01%, followed by Jiangxi (9.68%), Jiangsu (9.29%), Heilongjiang (8.68%), and Hubei (8.03%), as shown in Table 7.

3.2.3. Wheat

For district, the biggest straw production potential is from East district with a contribution of 37.50%, followed by Mid-South district (29.91%) and North district (15.02%). For province, Henan has the highest straw production potential with an input of 26.85%, followed by Shandong (17.98%), Hebei (10.80%), Anhui (10.32%), and Jiangsu (8.79%), as shown in Table 7.

3.3. Livestock manure resources

The livestock productions in China are mainly concentrating on pig (461.01×10^6 capita), sheep (282.85×10^6 capita) and cattle (105.77×10^6 capita). The livestock manure production is then calculated based on the parameters listed in Table 4. From 2007 to 2011, the biggest contribution to livestock manure production potential is primarily from cattle (1192.91×10^6 t), followed by pig (857.47×10^6 t) and sheep (208.55×10^6 t), as shown in Table 8.

3.3.1. Cattle

For district, the biggest cattle manure production potential is from South West district with a contribution of 28.08%, followed by Mid-South district (23.78%) and North West district (13.88%). For province, Henan has the highest cattle manure production potential with an input of 9.63%, followed by Sichuan (9.25%), Yunnan (6.93%), Neimenggu (6.36%), and Tibet (5.93%), as shown in Table 9.

3.3.2. Pig

For district, the biggest pig manure production potential is from Mid-South district with a contribution of 34.56%, followed by South West district (23.88%) and East district (21.84%). For province, Sichuan has the highest pig manure production potential with an input of 11.28%, followed by Henan (9.67%), Hunan (8.64%), Jiangxi (5.95%), and Yunnan (5.78%), as shown in Table 9.

3.3.3. Sheep

For district, the biggest sheep manure production potential is from North district with a contribution of 26.76%, followed by North West district (26.58%) and South West district (16.35%). For province, Neimenggu has the highest sheep manure production potential with an input of 18.34%, followed by Xinjiang (11.33%), Shandong (7.69%), Henan (6.88%), and Sichuan (5.99%), as shown in Table 9.

4. Results and analysis

4.1. Biogas potential of straw

According to Tables 4 and 6, the biogas potential of straw from different crops is calculated. The biogas potential of straw is continuously rising from 2007 to 2011, per the discussion in Section 3.2. The biggest contribution to biogas potential of straw is from grains, including corn (41.70%), paddy (23.73%), and wheat (15.33%), as shown in Fig. 4(a). The major contributors to total biogas potential of straw are Mid-South district (24.37%), East district (23.80%) and North East district (18.20%), as shown in Fig. 4(b). The dominant contributors to biogas potential of corn straw are North East district (30.57%), North district (22.24%) and East district (14.43%), as shown in Fig. 4(c). The key contributors to biogas potential of paddy straw are Mid-South district (35.29%), East district (33.10%) and South West district (15.75%), as shown in Fig. 4(d). The main contributors to biogas potential of wheat straw are East district (37.50%), Mid-South district (29.91%) and North district (15.02%), as shown in Fig. 4(e). For province, the largest contribution to biogas potential of straw is from Henan with a proportion of 10.37%, followed by Shandong (8.82%), Heilongjiang (8.55%), Hebei (6.08%), and Jilin (5.92%), as shown in Fig. 5(a).

4.2. Biogas potential of livestock manure

According to Tables 4 and 8, biogas potential of livestock manure from different animals is calculated. Though, biogas potential of livestock manure is fluctuating from 2007 to 2011, the variation between each year is quite small. The biggest contribution to biogas potential of livestock manure is from pig with a proportion of 46.62%, followed by cattle (43.24%) and sheep (7.56%), as shown in Fig. 6(a). The major contributors to biogas potential of livestock manure are Mid-South district (27.39%), South West district (25.30%) and East district (15.42%), as shown in Fig. 6(b). The main contributors to biogas potential of pig manure are Mid-South district (34.56%), South West district

Table 5
Crops production and straw production potential of different crops.

Crop	Crop Production (10^6 t)						Straw production potential (10^6 t)					
	2007	2008	2009	2010	2011	***Average***	2007	2008	2009	2010	2011	***Average***
Paddy	186.034	191.896	195.103	195.761	201.001	***193.959***	186.034	191.896	195.103	195.761	201.001	***193.959***
Wheat	109.298	112.464	115.115	115.181	117.401	***113.892***	120.228	123.710	126.627	126.699	129.141	***125.281***
Corn	152.300	165.914	163.974	177.245	192.781	***170.443***	304.601	331.828	327.947	354.490	385.562	***340.886***
Beans	17.201	20.433	19.303	18.965	19.084	***18.997***	29.242	34.736	32.815	32.241	32.443	***32.295***
Tubers	28.078	29.802	29.955	31.141	32.730	***30.341***	28.078	29.802	29.955	31.141	32.730	***30.341***
Cotton	7.624	7.492	6.377	5.961	6.589	***6.808***	22.871	22.476	19.130	17.883	19.767	***20.425***
Peanut	13.027	14.286	14.708	15.644	16.046	***14.742***	19.541	21.429	22.062	23.466	24.070	***22.114***
Rape	10.573	12.102	13.657	13.082	13.426	***12.568***	31.718	36.305	40.971	39.246	40.277	***37.703***
Sesame	0.557	0.586	0.622	0.587	0.605	***0.592***	1.114	1.173	1.244	1.173	1.211	***1.183***
Bast fiber plants	0.728	0.625	0.388	0.317	0.296	***0.471***	1.238	1.062	0.660	0.540	0.502	***0.800***
Sugarcane	112.951	124.152	115.587	110.789	114.434	***115.582***	11.295	12.415	11.559	11.079	11.443	***11.558***
Beets	8.931	10.044	7.179	9.296	10.731	***9.236***	0.893	1.004	0.718	0.930	1.073	***0.924***
Total	**756.853**			**807.837**		**808.790**	**834.649**		**879.220**			**817.470**

(23.88%) and East district (21.84%), as shown in Fig. 6(c). The dominant contributors to biogas potential of cattle manure are South West district (28.08%), Mid-South district (23.78%) and North West district (13.88%), as shown in Fig. 6(d). The key contributors to biogas potential of sheep manure are North district (26.76%), North West district (26.58%) and South West district (16.35%), as shown in Fig. 6(e). For province, the largest contribution to biogas potential of livestock manure is from Sichuan with a proportion of 9.94%, followed by Henan (9.25%), Yunnan (6.20%), Hunan (5.91%), and Shandong (5.48%), as shown in Fig. 5(b).

4.3. Total biogas potential

Total biogas potential is calculated according to the results from Sections 4.1 and 4.2. For district, the biggest total biogas potential

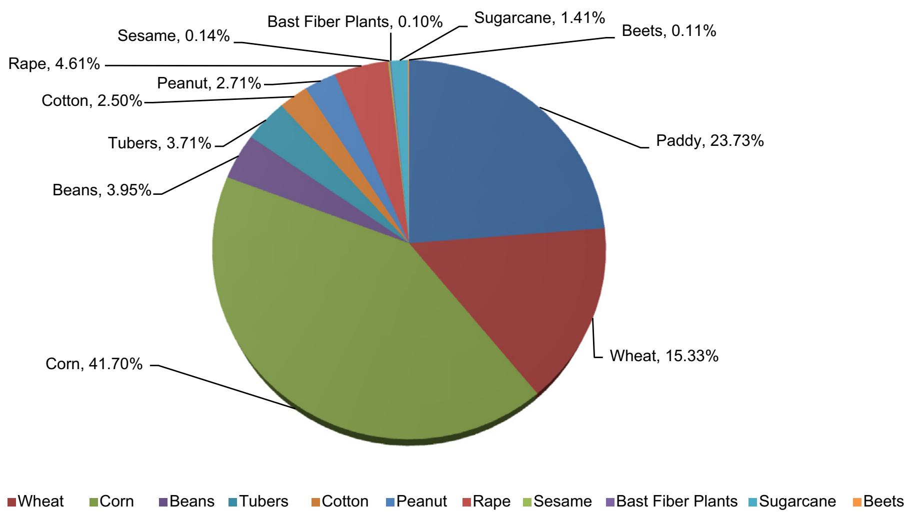

Fig. 3. Average contributions to straw production potential from different crops.

Table 6
Straw production potential in various regions.

District	Province	Abbr.	Straw production potential (10^6 t)						
			2007	2008	2009	2010	2011	Average	(%)
North	Beijing	BJG	1.852	2.212	2.211	2.053	2.175	2.101	*0.257*
	Tianjin	TJN	2.664	2.646	2.733	2.785	2.851	2.736	*0.335*
	Hebei	HEB	47.962	49.134	48.701	49.609	53.138	49.709	*6.081*
	Shanxi	SXI	16.847	17.891	16.354	18.837	20.740	18.134	*2.218*
	Neimenggu	NMG	30.654	36.127	34.253	37.296	41.189	35.904	*4.392*
North East	Liaoning	LNG	29.980	30.964	26.149	30.224	35.342	30.532	*3.735*
	Jilin	JLN	43.180	50.162	43.463	49.057	55.917	48.356	*5.915*
	Heilongjiang	HLJ	52.400	65.151	67.159	77.730	86.832	69.855	*8.545*
East	Shanghai	SGH	1.221	1.279	1.333	1.282	1.312	1.285	*0.157*
	Jiangsu	JSU	38.960	39.594	40.359	40.152	40.714	39.956	*4.888*
	Zhejiang	ZJG	8.488	9.293	9.479	9.183	9.345	9.158	*1.120*
	Anhui	ANH	39.530	41.786	42.819	42.360	43.188	41.937	*5.130*
	Fujian	FJN	6.991	7.238	7.407	7.370	7.511	7.303	*0.893*
	Jiangxi	JXI	21.617	22.394	23.191	22.873	24.048	22.825	*2.792*
	Shandong	SDG	69.838	71.993	72.469	72.281	73.873	72.091	*8.819*
Mid South	Henan	HEN	82.633	84.531	84.911	85.243	86.535	84.771	*10.370*
	Hubei	HUB	32.964	34.272	35.914	36.024	36.750	35.185	*4.304*
	Hunan	HUN	32.325	34.174	36.683	36.696	38.313	35.638	*4.360*
	Guangdong	GDG	15.882	15.593	16.520	16.621	17.284	16.380	*2.004*
	Guangxi	GXI	24.438	24.974	25.224	24.212	24.977	24.765	*3.029*
	Hainan	HAN	2.348	2.568	2.587	2.440	2.539	2.496	*0.305*
South West	Chongqing	CQG	14.332	15.225	15.197	15.569	15.379	15.140	*1.852*
	Sichuan	SCN	42.616	45.324	46.203	46.888	47.768	45.760	*5.598*
	Guizhou	GUZ	16.844	17.653	18.131	16.952	13.528	16.622	*2.033*
	Yunnan	YNN	21.892	24.071	25.311	24.663	27.243	24.636	*3.014*
	Tibet	TBT	0.546	0.564	0.544	0.547	0.568	0.554	*0.068*
North West	Shaanxi	SAX	17.327	17.940	18.584	18.945	19.482	18.456	*2.258*
	Gansu	GSU	11.296	12.324	12.960	14.316	15.364	13.252	*1.621*
	Qinghai	QGH	1.882	2.089	2.168	2.147	2.162	2.090	*0.256*
	Ningxia	NGX	4.661	4.860	5.028	5.278	5.377	5.041	*0.617*
	Xinjiang	XJG	22.675	23.802	24.738	25.006	27.771	24.798	*3.034*
Total			756.847	807.828	808.784	834.639	879.213	817.462	

Table 7
Straw production potential of different crops in various regions.

District	Province	Annual straw production potential (10^3 t)												
		Food crops					Cotton	Oil crops			Bast fiber plants	Sugar crops		Subtotal
		Grains			Beans	Tubers								
		Paddy	Wheat	Corn				Peanut	Rape	Sesame		Sugarcane	Beets	
North	Beijing	2.40	310.00	1,715.11	25.83	18.07	2.78	26.69	–	–	–	–	–	2,100.87
	Tianjin	107.36	581.88	1,780.92	26.42	4.22	229.13	5.75	–	–	–	–	–	2,735.67
	Hebei	569.96	13,534.88	29,910.20	655.76	920.40	1,973.77	1,988.68	83.84	21.23	2.32	–	47.74	49,708.78
	Shanxi	4.43	2,544.96	14,392.12	491.13	352.98	263.09	33.62	20.31	8.10	–	–	22.99	18,133.73
	Neimenggu	696.28	1,841.44	28,020.42	2,694.16	1,771.68	6.70	45.28	658.53	10.51	15.77	–	143.29	35,904.06
North East	Liaoning	4,958.60	48.62	23,322.80	663.34	512.50	4.11	1,008.68	2.63	4.19	–	–	6.28	30,531.75
	Jilin	5,552.01	15.23	40,144.00	1,692.82	419.80	14.96	481.81	–	22.02	1.19	–	11.98	48,355.82
	Heilongjiang	16,832.85	1,036.00	40,737.73	9,886.48	917.96	–	84.30	4.95	5.19	143.69	–	205.44	69,854.59
East	Shanghai	889.02	216.28	50.92	28.29	5.36	9.98	4.00	80.00	–	–	1.50	–	1,285.35
	Jiangsu	18,015.84	11,016.90	4,244.09	1,439.71	408.98	861.84	548.31	3,369.88	36.36	4.47	9.35	0.02	39,955.75
	Zhejiang	6,522.34	251.96	238.00	516.66	378.76	86.22	74.71	998.38	15.75	1.00	73.91	–	9,157.70
	Anhui	13,831.91	12,933.25	6,066.50	2,093.05	470.84	1,066.62	1,156.38	4,106.77	136.61	50.74	23.77	0.07	41,936.51
	Fujian	5,094.45	12.96	287.41	303.57	1,133.74	0.55	363.64	42.00	2.94	–	62.13	–	7,303.39
	Jiangxi	18,765.66	22.18	156.74	466.89	593.52	382.97	593.40	1,708.81	56.43	18.78	59.29	–	22,824.67
	Shandong	1,085.78	22,527.08	38,144.48	716.04	1,838.40	2,682.88	5,013.48	78.71	3.17	0.54	–	0.02	72,090.58
Mid South	Henan	4,552.64	33,643.35	32,651.28	1,596.23	1,370.04	1,648.71	6,084.45	2,653.40	472.37	74.75	23.68	–	84,770.90
	Hubei	15,572.44	3,744.22	4,851.36	743.14	886.30	1,529.30	905.74	6,585.97	270.07	68.16	28.13	–	35,184.84
	Hunan	25,227.40	72.38	3,043.20	643.42	1,123.60	694.08	371.40	4,217.39	23.04	147.42	74.81	–	35,638.13
	Guangdong	10,529.90	2.92	1,393.41	306.37	1,596.56	–	1,256.35	24.10	4.65	0.90	1,264.64	–	16,379.80
	Guangxi	11,142.80	5.45	4,359.67	420.43	594.21	6.30	594.57	40.27	11.25	19.65	7,570.41	–	24,765.01
	Hainan	1,419.47	–	165.17	29.15	312.06	–	128.19	–	5.25	1.64	435.39	–	2,496.33
South West	Chongqing	5,088.71	570.34	4,932.88	673.70	2,798.54	–	124.32	900.27	13.81	26.32	11.50	–	15,140.39
	Sichuan	14,953.46	4,764.09	13,013.63	1,757.46	4,354.54	45.52	883.00	5,768.46	9.47	111.49	98.65	0.23	45,760.01
	Guizhou	4,227.37	462.88	7,250.54	536.07	2,072.18	2.66	97.28	1,911.40	–	1.58	59.77	–	16,621.73
	Yunnan	6,264.32	905.10	11,128.24	1,794.45	1,713.22	–	85.17	957.49	–	27.71	1,760.16	0.07	24,635.93
	Tibet	5.54	277.18	47.84	44.10	4.08	–	–	175.01	–	–	–	–	553.74
North West	Shaanxi	808.18	4,286.46	10,346.02	793.05	770.62	247.80	129.96	1,031.96	39.60	0.89	1.15	0.09	18,455.77
	Gansu	30.48	2,783.04	6,546.60	598.09	2,053.48	299.76	2.96	908.09	–	7.55	–	21.68	13,251.74
	Qinghai	–	473.22	133.46	167.35	324.54	–	–	991.01	–	–	–	0.15	2,089.71
	Ningxia	664.44	731.52	3,164.46	60.31	419.51	–	–	0.54	–	–	–	0.07	5,040.86
	Xinjiang	542.90	5,665.18	8,646.52	431.90	200.68	8,363.63	21.02	382.38	8.88	71.69	–	463.42	24,798.20
Total		**193,958.93**	**125,280.94**	**340,885.72**	**32,295.37**	**30,341.38**	**20,423.36**	**22,113.11**	**37,702.52**	**1,180.92**	**798.27**	**11,558.26**	**923.54**	**817,462.32**

Table 8
Livestock production and livestock manure production potential of different animals.

Livestock	Livestock Production (10^6 capita)						Livestock manure production potential (10^6 t)					
	2007	2008	2009	2010	2011	***Average***	2007	2008	2009	2010	2011	***Average***
Cattle	105.948	105.760	107.265	106.264	103.605	***105.768***	1,194.933	1,192.814	1,209.792	1198.502	1168.505	***1192.909***
Horse	7.028	6.821	6.785	6.771	6.709	***6.823***	40.208	39.024	38.819	38.737	38.383	***39.034***
Donkey	6.891	6.731	6.484	6.397	6.478	***6.596***	22.022	21.511	20.721	20.441	20.701	***21.079***
Mule	2.985	2.955	2.793	2.697	2.598	***2.805***	9.536	9.442	8.925	8.619	8.301	***8.965***
Camel	0.242	0.240	0.248	0.256	0.273	***0.252***	2.272	2.254	2.331	2.406	2.570	***2.367***
Pig	439.895	462.913	469.960	464.600	467.669	***461.008***	818.204	861.019	874.126	864.156	869.865	***857.474***
Sheep	285.647	280.849	284.522	280.879	282.358	***282.851***	210.608	207.070	209.778	207.092	208.182	***208.546***
Total							**2297.783**	**2333.134**	**2364.491**	**2339.954**	**2316.507**	**2330.374**

Table 9
Livestock manure production potential of different animals in various regions.

District	Province	Livestock manure production potential (10^6 t)						
		Cattle	Horse	Donkey	Mule	Camel	Pig	Sheep
North	Beijing	2.48	0.01	0.03	0.01	–	3.34	0.50
	Tianjin	3.13	0.01	0.02	0.01	–	3.30	0.27
	Hebei	48.67	1.20	2.09	0.81	–	35.79	11.25
	Shanxi	10.64	0.11	0.65	0.58	–	8.53	5.53
	Neimenggu	73.90	4.08	2.91	1.13	0.90	12.40	38.25
North East	Liaoning	39.46	1.51	3.60	0.67	–	28.91	5.21
	Jilin	53.11	2.65	0.69	0.40	–	18.77	3.06
	Heilongjiang	59.28	1.59	0.27	0.11	–	24.51	6.45
East	Shanghai	0.77	–	–	–	–	3.02	0.16
	Jiangsu	3.86	0.03	0.14	0.04	–	31.88	3.05
	Zhejiang	2.27	0.00	–	–	–	22.16	0.82
	Anhui	16.57	0.01	0.01	0.00	–	26.63	4.22
	Fujian	7.76	–	–	–	–	24.20	0.73
	Jiangxi	29.07	–	–	–	–	28.31	0.42
	Shandong	57.64	0.29	0.50	0.11	–	51.04	16.03
Mid South	Henan	114.85	0.80	0.64	0.20	–	82.93	14.36
	Hubei	36.36	0.05	0.01	0.00	–	45.79	2.83
	Hunan	47.92	0.24	0.02	0.01	–	74.11	3.76
	Guangdong	25.91	0.01	–	–	–	43.16	0.28
	Guangxi	48.69	2.25	0.00	0.16	–	43.02	1.35
	Hainan	9.94	–	–	–	–	7.37	0.50
South West	Chongqing	12.86	0.13	0.01	0.03	–	28.61	1.09
	Sichuan	110.39	5.62	0.33	0.35	–	96.73	12.50
	Guizhou	58.30	4.87	0.00	0.11	–	29.36	1.81
	Yunnan	82.72	4.29	1.13	2.16	–	49.55	6.38
	Tibet	70.76	2.30	0.28	0.06	–	0.55	12.33
North West	Shaanxi	18.41	0.05	0.54	0.21	–	16.43	4.86
	Gansu	48.28	0.79	3.24	1.38	0.15	10.50	12.54
	Qinghai	50.30	1.19	0.19	0.27	0.08	1.99	11.05
	Ningxia	10.48	0.02	0.28	0.11	0.00	1.51	3.35
	Xinjiang	38.17	4.91	3.50	0.04	1.24	3.07	23.62
Total		1192.91	39.03	21.08	8.96	2.37	857.47	208.55

is from Mid-South district with a proportion of 25.97%, followed by East district (19.36% averagely) and South West district (19.31% averagely), as shown in Fig. 7(a). For province, the largest contribution to total biogas potential is from Henan with a proportion of 9.79%, followed by Sichuan (7.90%), Shandong (7.05%), Heilongjiang (6.03%), and Hunan (5.18%).

4.3.1. *Biogas potential of straw*

For district, about 60.91% of total biogas potential is from biogas potential of straw in North East district, followed by East district (57.84%) and North district (51.71%), as shown in Fig. 7(b). For province, around 68.57% of total biogas potential is contributed by biogas potential of straw in Jiangsu, followed by Anhui (67.43%), Heilongjiang (66.73%), Shanxi (64.22%), and Jilin (62.22%), as shown in Fig. 8.

4.3.2. *Biogas potential of livestock manure*

For district, about 69.37% of total biogas potential is from biogas potential of livestock manure in South West district, followed by North West district (60.26%) and Mid-South district (55.84%), as shown in Fig. 7(b). For province, around 98.12% of total biogas potential is contributed by biogas potential of livestock manure in Tibet, followed by Qinghai (91.33%), Hainan (74.16%), Yunnan (69.82%), and Guizhou (68.64%), as shown in Fig. 8.

In general, about 47.06% of total biogas potential is from straw and the other 52.94% is from livestock manure, as shown in Fig. 8.

4.4. *Biogas potential density*

Biogas potential density is the indicator to reveal the biogas production efficiency in various regions.

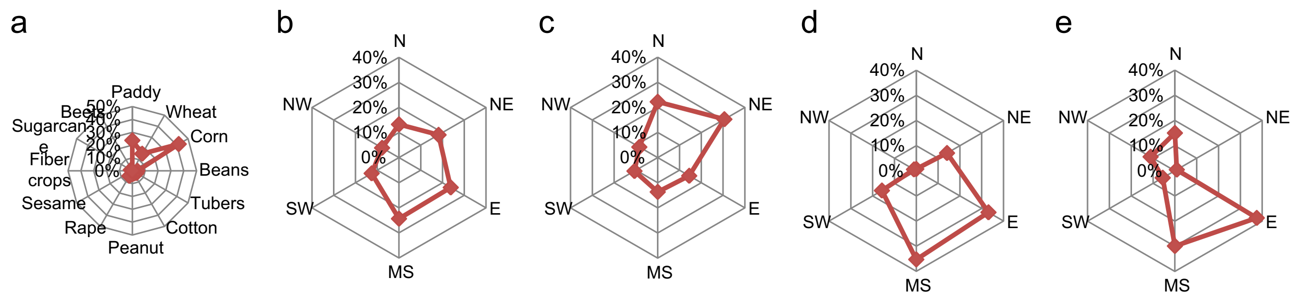

Fig. 4. Allocation of biogas potential of straw. (a) Biogas potential of straw from different crops. (b) Biogas potential of straw in various regions. (c) Biogas potential of corn in various regions. (d) Biogas potential of paddy in various regions and (e) Biogas potential of wheat in various regions.

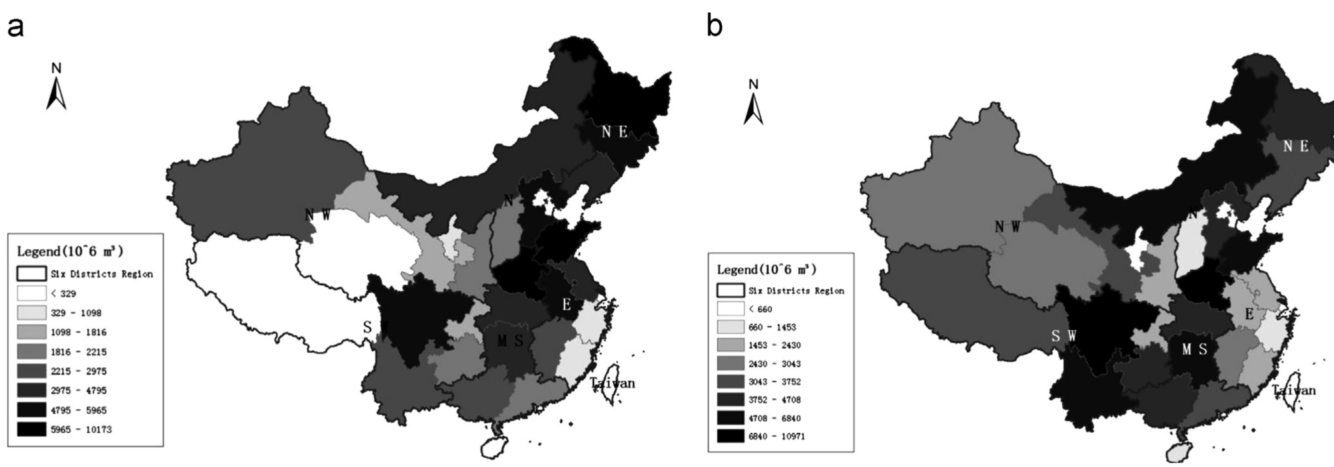

Fig. 5. Biogas potential in various regions. (a) Biogas potential of straw in various regions and (b) Biogas potential of livestock manure in various regions.

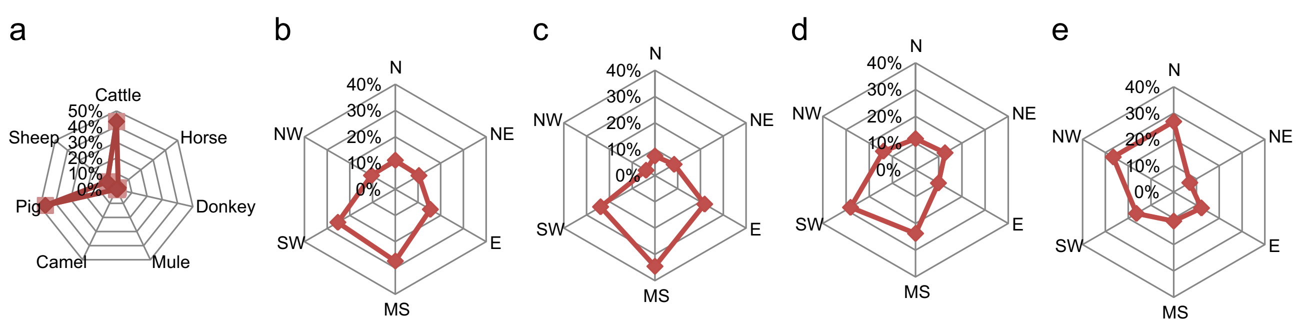

Fig. 6. Allocation of biogas potential of livestock manure. (a) Biogas potential of livestock manure from different animals. (b) Biogas potential of livestock manure in various regions. (c) Biogas potential of pig in various regions. (d) Biogas potential of cattle in various regions and (e) Biogas potential of sheep in various regions.

4.4.1. Biogas potential density of straw per arable land ($BPOD_s$)

The national average biogas potential density of straw per arable land, the indicator of biogas potential efficiency of arable land from straw, is 80.33×10^3 m^3/km^2. For district, Mid-South district has the highest $BPOD_s$ with the amount of 98.98×10^3 m^3/km^2, followed by East district (95.95×10^3 m^3/km^2) and North East district (83.21×10^3 m^3/km^2). For province, Henan has the highest $BPOD_s$ with the amount of 128.34×10^3 m^3/km^2, followed by Shandong (115.11×10^3 m^3/km^2), Hunan (112.86×10^3 m^3/km^2), Beijing (108.81×10^3 m^3/km^2), and Jilin (104.84×10^3 m^3/km^2), while there are about 16 provinces with $BPOD_s$ higher than the national average, as shown in Fig. 9(a).

4.4.2. Biogas potential density per arable land and grassland ($BPOD_{ag}$)

The national average biogas potential density per arable land and grassland, the indicator of biogas potential efficiency of arable land and grassland from agricultural and livestock waste, is 40.48×10^3 m^3/km^2, which is only half of $BPOD_s$. For district, East district has the highest $BPOD_{ag}$ with the amount of 106.84×10^3 m^3/km^2, followed by Mid-South district (99.83×10^3 m^3/km^2) and North East district (76.68×10^3 m^3/km^2). For province, Henan has the highest $BPOD_{ag}$ with the amount of 164.90×10^3 m^3/km^2, followed by Shandong (160.56×10^3 m^3/km^2), Jiangsu (135.08×10^3 m^3/km^2), Shanghai (117.47×10^3 m^3/km^2), and Tianjin (112.94×10^3 m^3/km^2), while there are 20 provinces with $BPOD_{ag}$ higher than the national average, as shown in Fig. 9(b).

4.4.3. Biogas potential density per area ($BPOD_a$)

The national average biogas potential density per area, the indicator of biogas potential efficiency of land in a region, is 21.69×10^3 m^3/km^2, which is about one quarter of $BPOD_s$. For district, Mid-South district has the highest $BPOD_a$ with the amount

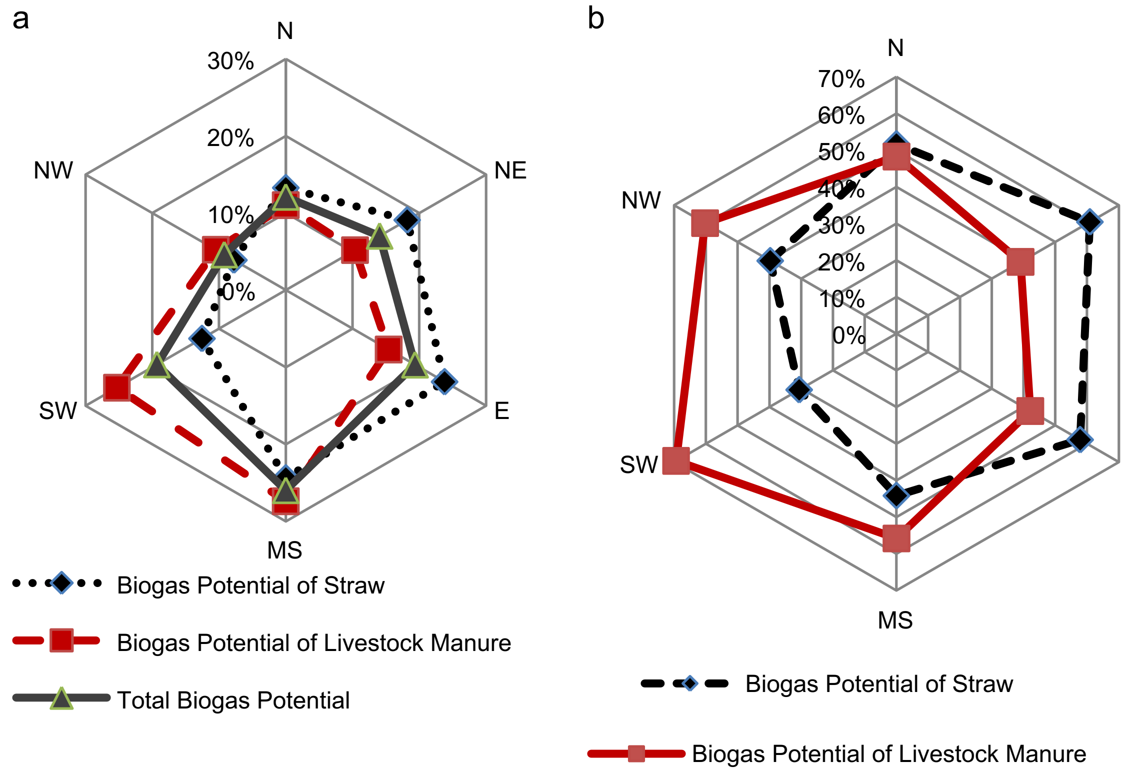

Fig. 7. Allocation of biogas potential in various regions. (a) Allocation of biogas potential in various regions and (b) Proportion of biogas potential of straw and livestock manure in various regions.

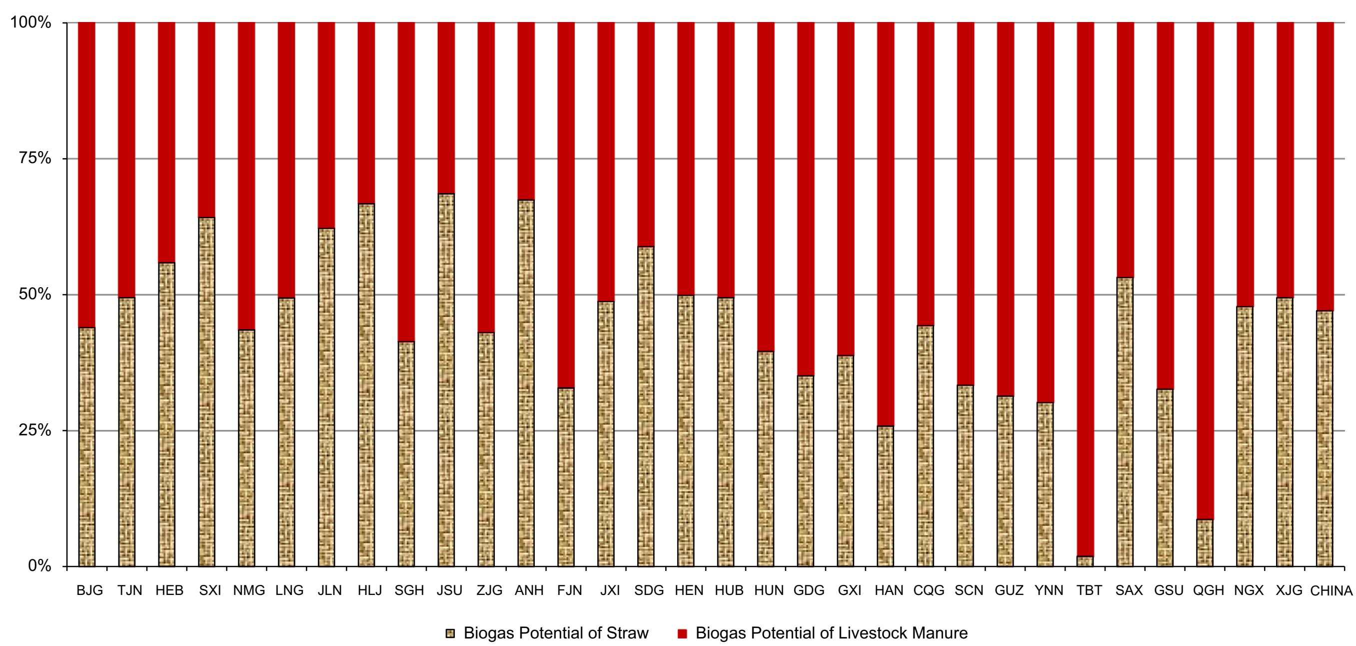

Fig. 8. Percentage of biogas potential of straw and livestock manure in various regions.

of 53.35×10^3 m^3/km^2, followed by East district (50.93×10^3 m^3/km^2) and North East district (37.18×10^3 m^3/km^2). For province, Henan has the highest $BPOD_a$ with the amount of 122.05×10^3 m^3/km^2, followed by Shandong (95.55×10^3 m^3/km^2), Jiangsu (68.15×10^3 m^3/km^2), Shanghai (59.17×10^3 m^3/km^2), and Tianjin (58.74×10^3 m^3/km^2), while there are 23 provinces with $BPOD_a$ higher than the national average, as shown in Fig. 9(c).

4.5. Actual biogas production

According to the China Statistical Yearbook on Environment, actual biogas production and biogas production from large- and medium-scale biogas engineering projects in various regions from 2003 to 2011 are collected to demonstrate the trend of continuously rising each year, as shown in Fig. 10(a). However, in order to

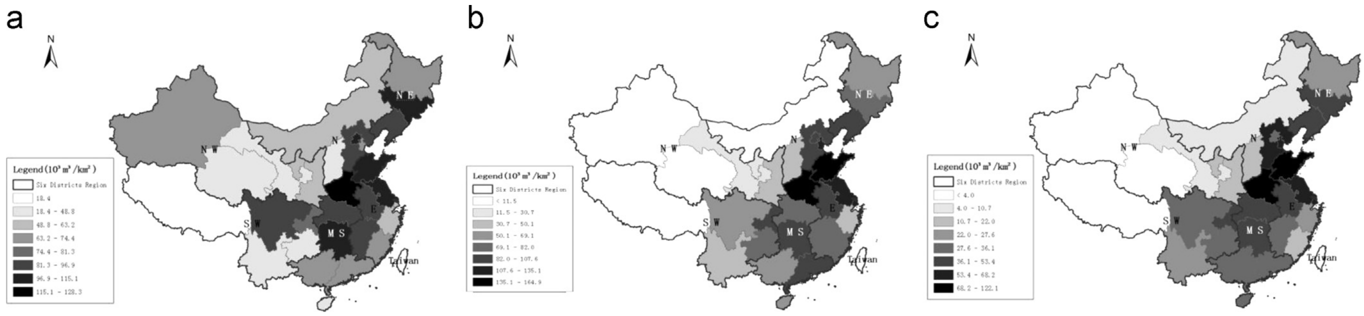

Fig. 9. Biogas potential density in various regions. (a) Biogas potential density of straw per arable land. (b) Biogas potential density per arable land and grassland and (c) Biogas potential density per area.

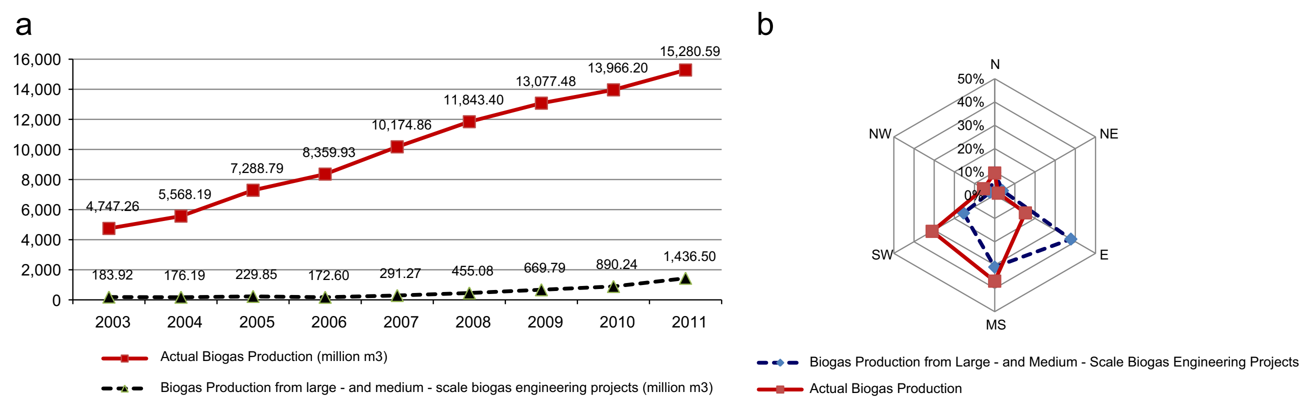

Fig. 10. Biogas production in each year and biogas production allocation in various regions. (a) Biogas production in each year and (b) Allocation of biogas production in various regions.

be comparable with biogas potential analysis, the following statistical data are all calculated from 2007 to 2011.

4.5.1. Actual biogas production

For district, main actual biogas production is from Mid-South district with the contribution of 36.90%, followed by South West district (31.03%) and East district (15.22%), as shown in Fig. 10(b). For province, the highest actual biogas production is from Sichuan with a contribution of 13.67%, followed by Guangxi (10.64%), Henan (9.03%), Yunnan (8.52%), and Hebei (7.01%), as shown in Fig. 11(a).

The national average biogas production density (BPRD), the indicator of biogas production efficiency of land in a region, is only 1.34×10^3 m^3/km^2 for whole nation. For district, Mid-South district has the highest BPRD with the amount of 4.68×10^3 m^3/km^2, followed by East district (2.47×10^3 m^3/km^2) and South West district (1.70×10^3 m^3/km^2). For province, Hainan has the highest BPRD with the amount of 7.76×10^3 m^3/km^2, followed by Henan (6.96×10^3 m^3/km^2), Guangxi (5.80×10^3 m^3/km^2), Hebei (4.80×10^3 m^3/km^2), and Hubei (4.67×10^3 m^3/km^2), while there are about 16 provinces with BPRD higher than the national average, as shown in Fig. 11(b).

4.5.2. Biogas production from large- and medium-scale biogas engineering projects

For district, biogas production from large- and medium-scale biogas engineering projects is mainly coming from Mid-South district with the contribution of 37.78%, followed by East district (30.88%) and South West district (15.43%), as shown in Fig. 10(b). For province, the highest biogas production from large- and medium-scale biogas engineering projects is contributed by Sichuan Shandong with a proportion of 12.68%, followed by Henan (10.09%), Zhejiang (9.71%), Shandong (9.50%), and Hainan (6.89%), as shown in Fig. 11(c).

The national average biogas production density of biogas engineering projects ($BPRD_p$), the indicator of biogas production efficiency of large- and medium scale biogas engineering projects in a region, is only 0.08×10^3 m^3/km^2 for entire nation. For district, East district has the highest $BPRD_p$ with the amount of 0.35×10^3 m^3/km^2, followed by Mid-South district (0.23×10^3 m^3/km^2) and South West district (0.05×10^3 m^3/km^2). For province, Hainan has the highest $BPRD_p$ with the amount of 1.51×10^3 m^3/km^2, followed by Beijing (1.07×10^3 m^3/km^2), Zhejiang (0.71×10^3 m^3/km^2), Shandong (0.46×10^3 m^3/km^2), and Henan (0.45×10^3 m^3/km^2), while there are about 18 provinces with $BPRD_p$ higher than the national average, as shown in Fig. 11(d).

5. Discussions

Per the results and analysis described earlier, several conclusions can be drawn as illustrated in the following.

5.1. Significant regional differences

There are great regional differences in biogas potential between districts and provinces. For example, about 64.64% of total biogas potential in China is allocated among Mid-South district, East district and South West district that is quite similar to the allocation of biogas potential of livestock manure. In other words, biogas potential of livestock manure plays more vital role in contributing to total biogas potential, especially for Mid-South district and South West district. Moreover, in these two districts, nearly 31.30% of total biogas potential in China is allocated among Sichuan, Henan, Hunan, and Yunnan, where pig and cattle are two

dominant contributors to total biogas potential. Though biogas potential of livestock manure has a bigger proportion (60.26%) in contributing to total biogas potential in North West district, total biogas potential is the least one among six districts, due to smaller biogas potential of livestock manure. For other districts where biogas potential of straw has larger contribution to total biogas potential, total biogas potential is comparatively smaller, except for East district.

Noticeably, there are two districts, Mid-South and East districts, with higher contributions from both biogas potential of straw and livestock manure. About 24.37% of biogas potential of straw and 27.39% of biogas potential of livestock manure are contributed by Mid-South district to make a contribution of 25.79% to total biogas potential in China. Around 23.80% of biogas potential of straw and 15.42% of biogas potential of livestock manure are contributed by East district to make a contribution of 19.36% to total biogas potential in China.

5.2. Low exploitation and utilization rates

While comparing the actual biogas production with total biogas potential, the ratio of actual biogas production to total biogas potential

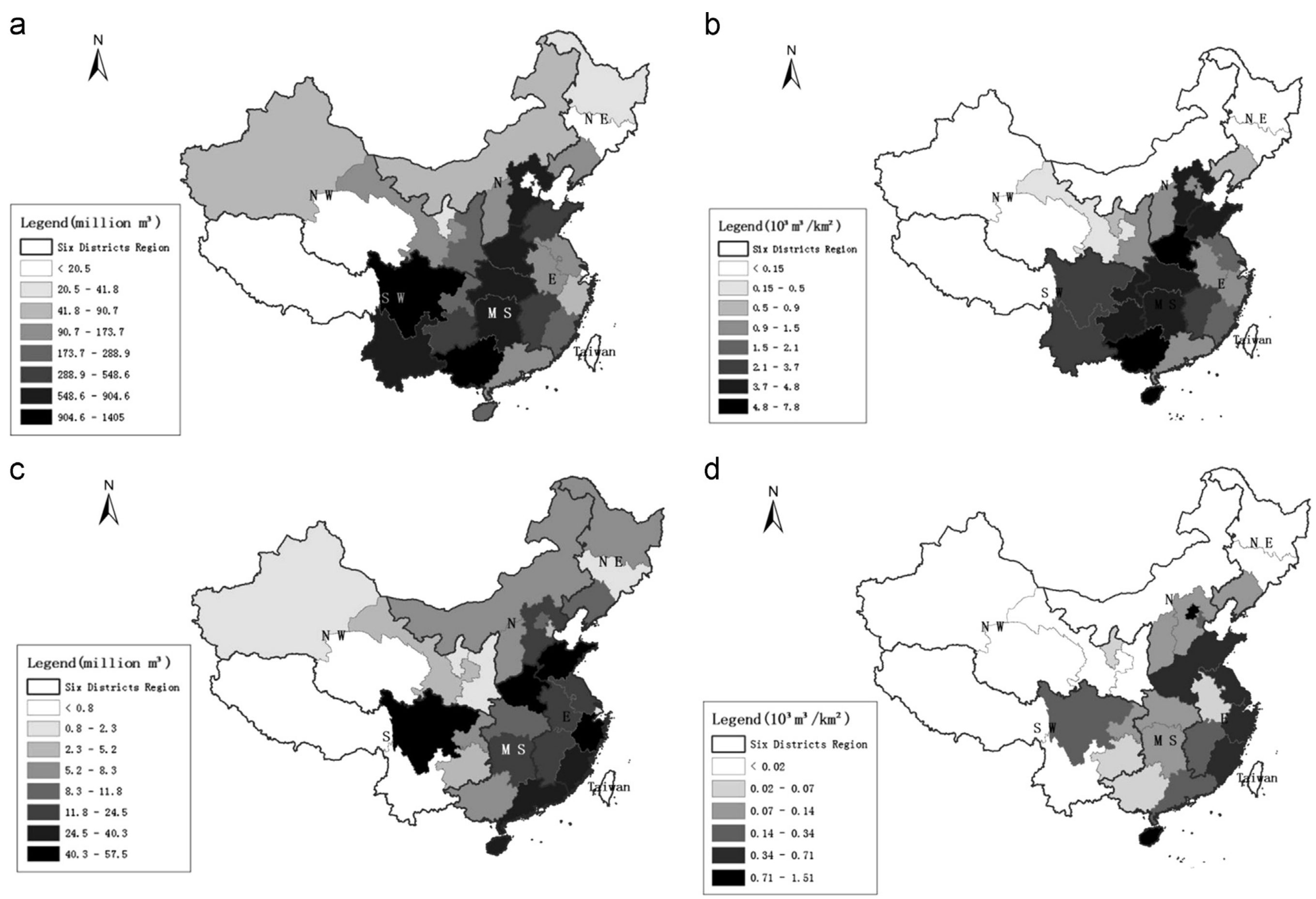

Fig. 11. Biogas production and biogas production density in various regions. (a) Biogas production in various regions. (b) Biogas production density in various regions. (c) Biogas production from large- and medium-scale biogas engineering projects in various regions and (d) Biogas production density from large- and medium-scale biogas engineering projects in various regions.

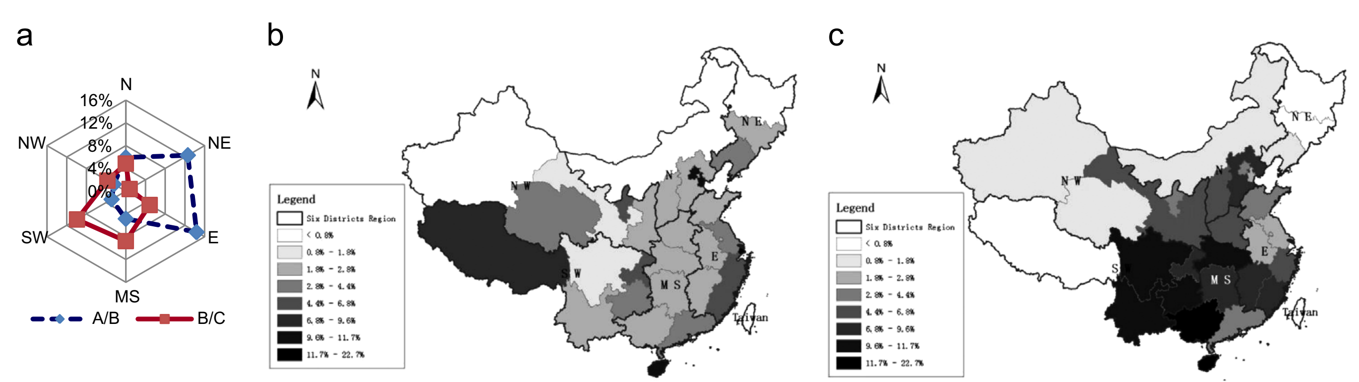

Fig. 12. Biogas potential density in various regions A/B: biogas production from large- medium-scale biogas engineering projects/actual biogas production B/C: actual biogas production/total biogas potential. (a) Allocation of exploitation and utilization rate of biogas. (b) Biogas exploitation rate in various regions and (c) Biogas utilization rate in various regions.

has been increasing repetitively, since 2007, with a percentage of 6.17%. Nevertheless, this exploitation rate is way too low. For district, the highest ratio of actual biogas production to total biogas potential is in South West district with a percentage of 9.92%, followed by Mid-South district (8.77%) and North district (4.86%), as shown in Fig. 12(a). For province, the highest ratio of actual biogas production to total biogas potential is in Hainan with a proportion of 22.77%, followed by Guangxi (17.88%), Guizhou (11.67%), Yunnan (11.18%), and Sichuan (10.68%), as shown in Fig. 12(b).

When considering the ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production, it also demonstrates a continuously growing trend, with a percentage of 5.79%. Still, this utilization rate is also quite low. For district, the highest ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production is in East district with a percentage of 14.37%, followed by North East district (12.61%) and North district (5.92%), as shown in Fig. 12(a). For province, the highest ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production is in Shanghai with a percentage of 100%, due to quite low actual biogas production, followed by Beijing (85.58%), Zhejiang (54.33%), Tianjin (27.34%), and Jiangsu (21.45%), as shown in Fig. 12(c).

5.3. Imbalanced resources allocation

According to the analysis discussed in Section 4.5, in East district, the contribution to biogas production from large- and medium-scale biogas engineering projects and the ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production are both the highest among all districts, though the biogas production is ranked in the third. In addition, most provinces in East district, including Zhejiang, Shandong, Fujian, Jiangsu, and Jiangxi, have bigger contribution to biogas production from large- and medium-scale biogas engineering projects and higher ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production.

On the contrary, even with very high portion of biogas production in South West district, the contribution to biogas production from large- and medium-scale biogas engineering projects and the ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production are both quite low. Moreover, most provinces in South West district, including Chongqing, Guizhou, Yunnan, and Tibet, have smaller contribution to biogas production from large- and medium-scale biogas engineering projects and lower ratio of biogas production from large- and medium-scale biogas engineering projects to actual biogas production.

Therefore, it is presumably that most of the investment and available resources on biogas engineering projects are allocated to more developed and easily accessible areas, such as East and Mid-South districts.

5.4. Low return on investment

Entering the 21st century, the Chinese government has been investing a huge amount of capital (more than ¥32 $\times$ 10^9) on biogas production, as illustrated in Table 3. Nevertheless, the cost for per m^3 increment of biogas production is continuously rising, particularly from 2006 to 2010, as shown in Fig. 13. For example, the highest cost for per m^3 increment of biogas production is ¥5.85/m^3 in 2010 and the lowest one is ¥0.22/m^3 in 2003. Considering the inflation between 2003 and 2010, the cost for per m^3 increment of biogas production in 2003 will then be equivalent to ¥0.43/m^3 (with an annual discount rate of 10%), which is still the lowest one. In other words, the return on investment is lowest one in 2010 and highest one in 2003, relatively. Again, the cost for biogas engineering projects will be much higher in more developed and easily accessible areas, due to rapidly rising labor wages in these areas.

6. Recommendations

In order to promote the development of biogas industry and facilitate the biogas exploitation and utilization rate in China, several important measures should be made.

6.1. Comprehensive resources assessment

As illustrated earlier, due to significant geographical/meteorological differences and regional characteristics, there are great disparities between land resources, crop resources and livestock resources in various regions. Hence, in order to promote the exploitation and utilization rates, a comprehensive resources assessment should be executed to learn the most appropriate resource utilization, the best applicable technology, and the most effective management scheme for various regions. In addition, since diverse problems could be encountered in various regions, the technical consulting and after-service

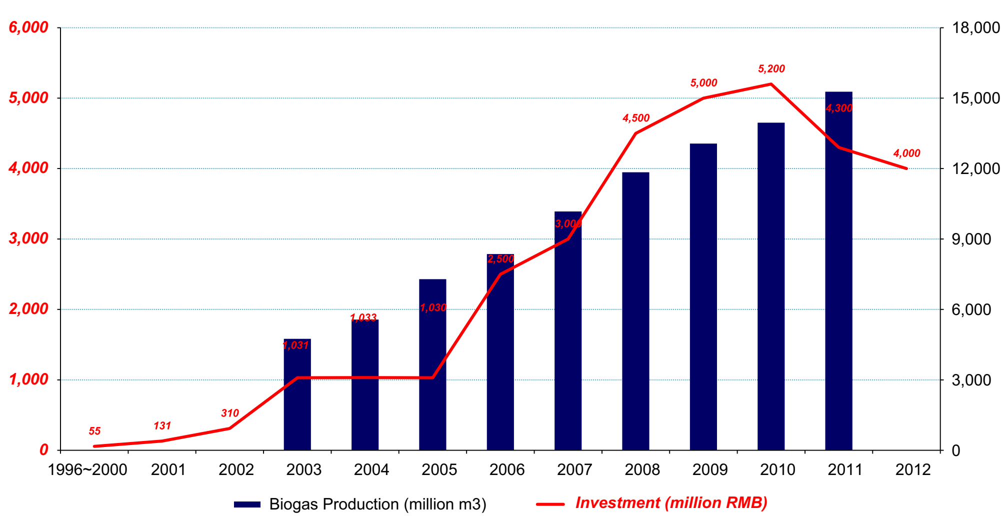

Fig. 13. Actual biogas production and the investment on biogas production.

system or platform should be established to provide necessary consultancy and technical support on construction, management, operation and maintenance for various scales biogas engineering projects, as well as household biogas.

6.2. Regionalized management scheme

Since there are significant regional differences, it is necessary to institute the regionalized management scheme for the development of biogas industry, based upon geographical characteristics and resources allocations. For example, through spatial economics model, a spatial analysis on environmental and resource economics should be conducted thoroughly to ascertain the financial status, economic levels, industrial structure, different levels of development, social infrastructure, local needs, etc. Different management schemes and standards should be instituted and implemented to promote the regional sustainable development.

6.3. Effective capital allocation scheme

Indeed, it would be much more convenient to construct large- and medium-scale biogas engineering projects in more developed and easily accessible areas. However, the labor cost and other miscellaneous expense could be much higher. In addition, the biogas potentials of livestock manure in these regions are generally quite low. Therefore, in order to ensure effective mass production of biogas to increase the return on investment, it is necessary to perform the comprehensive assessment on biogas potential and a complete cost-effective analysis, prior to the capital allocation for biogas engineering projects. Proper capital allocation should then be apportioned to corresponding areas with maximum productivity and highest return on investment.

7. Conclusions

In order to enhance the energy structure, improve the status of the 3-Agros, to facilitate environmental protection, and to attain sustainable development, biogas, as one source of renewable energy, has been one of the focal points for many years in China. In promoting the utilization of renewable energy, a number of policies, laws, regulations, ordinances, reports and other official documents have been promulgated, and numerous capital have been invested to ensure there will be sufficient motivations and incentives to encourage the development of biogas industry. Nevertheless, even if with enormous biogas potential, the accomplishments are localized and limited due to significant geographical differences, diverse regional characteristics, and probably inappropriate management schemes and capital allocations. For example, the highest biogas production from large- and medium-scale biogas engineering projects is from East district, even though the biogas potential and biogas production in Mid-South district are both the highest one among all six districts. In order to promote the sustainable development of biogas industry, to elevate the exploitation and utilization rates of biogas potential, and to increase the return on the investment on biogas engineering projects, some recommendations are provided as in the following. First is to conduct a comprehensive resource assessment to learn the allocations of various resources, such as agricultural waste and animal waste, in order to achieve higher exploitation and utilization rates of biogas potential. Second is to institute regionalized management scheme to increase the effectiveness and efficiency of governmental policy, according to geographical differences, regional characteristics, and resource allocations. Third is to adopt proper and effective capital allocation scheme to greatly increase the return on investment and facilitate regionalized development of biogas industry.

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